REMARKS/ARGUMENTS

Reconsideration and withdrawal of the rejections of the application are respectfully requested in view of the amendments and remarks herewith, which place the application into condition for allowance. The present response is being made to facilitate prosecution of the application.

I. STATUS OF THE CLAIMS AND FORMAL MATTERS

Claims 1-13 and 23-29 and 31-36 are pending in this application. Claims 1, 23 and 33 and 35 are amended hereby. Support can be found throughout the specification.

Claims 34 and 36 are rejected under 35 U.S.C. §112 first paragraph as allegedly lacking written description. Claims 1-2, 4, 6-8, 13, 23, 25-27, and 31-36 are rejected under 35 U.S.C. §112, second paragraph for allegedly being indefinite. Claims 1-2, 4, 6, 13, 23, 25-27, 31, and 33-36 are rejected under 35 U.S.C. §102 or §103 over International Pat. Pub. No. WO 01/25522 to Noelle ("Noelle"); U.S. Pat. Pub 2002/01606851 is cited for the translation. Claims 23, 25-27, 31, 32 and 35-36 are rejected under 35 U.S.C. §102 or §103 over U.S. Pat. No. 5,857,497 to Gassier ("Gassier"). Claims 1-2, 4, 6, 13, 23, 25-27, 31, and 33-36 are rejected under 35 U.S.C. §102 or §103 over U.S. Pat. No. 6,074,966 to Zlatkus ("Zlatkus"). Claims 2-4, 6-8, 13 and 32-36 are rejected under 35 U.S.C. §103 over Noelle in view of Gassier. Claims 1-2, 4, 6, 13, 23, 25-27, 31, and 33-36 are rejected under 35 U.S.C. §103 over Gassier in view of International Pat. Pub. No. WO 01/88261 to Strandqvist ("Strandqvist"). Claims 2-4, 6-8, 13 and 32-36 are rejected under 35 U.S.C. §103 over Zlatkus in view of Gassier. Claims 1-2, 4, 6, 13, 23, 25-27, 31, and 33-36 are rejected under 35 U.S.C. §103 over Strandqvist in view of U.S. Pat. No. 3,790,438 to Lewis ("Lewis"). Claims 1-2, 4, 6, 13, 23, 25-27, 31, and 33-36 are rejected under 35 U.S.C. § 103(a) over U.S. Patent No. 5,142,752 to Greenway ("Greenway") in view of either Noelle, Zlatkus, or U.S. Pat. No, 5,915,422 to Fagerholm ("Fagerholm"). Claims 2-4, 6-8, 13 and 32-36 are rejected under 35 U.S.C. §103 over Greenway in view of either Noelle, Zlatkus, of Fagerholm, and further in view of Gassier. Claims 23, 25-27 and 31 are rejected under 35 USC § 103 (a) over U.S. Patent No. 5,883,022 to Elsener ("Elsener") in view of any one of U.S. Patent No. 3,884,630 to Schwartz ("Schwartz") or U.S. Patent No. 4,104,814 to Whight ("Whight"). For the reasons reasons given in the prior responses and the

Appeal Brief, the entirety of which is incorporated hereby and not repeated here, as well as below, Applicants traverse and respectfully request reconsideration and withdrawal of the rejections.

II. CLAIMS 34 AND 36 ARE PATENTABLE UNDER 35 U.S.C. § 112, FIRST PARAGRAPH

Claims 34 and 36 are rejected under 35 U.S.C. §112 first paragraph as allegedly lacking written description. Claims 34 an 36 each recite: "the liquid is jetted from the hydroentangling apparatus at pressures from at least 200 psi." As was discussed throughout prosecution, and explained in the prior response: column 2 line 25 to column 4, line 3 of U.S. Patent 6,163,943 (the '943 patent") is incorporated by reference at paragraph 12 of the published application. The '943 patent in turn refers to CA patent no 841,938 (see'943 patent at col. 3, lines 54-56). Appellants also submitted as evidence U.S. Patent No. 4,967,456, of record in the present application. **The evidence shows that hydroentangling apparatuses "jetting water supplied at pressures of 200 to 2000 pounds per square inch (psi)." CA 841,938. (See also US 4,967,456: "First and second stage enhancement is preferably effected by columnar fluid jets which impact the fabric at pressures within the range of 200 to 3000 psi and impart a total energy to the fabric of approximately 0.10 to 2.0 hp-hr/lb.")**

Appellants also noted that that as such properties are well known, stating:

> As explained in the Background of '943 Patent "Hydroentangling or spunlacing is a technique introduced during the 1970'ies [sic], see e g CA patent no. 841 938." Hence there is ample support for the amendments with respect to such properties with or without incorporating the above-noted documents by reference into the present specification. (See *Falkner v. Inglis*, 79 USPQ2d 1001 (Fed. Cir. 2006), showing the recitation of known structure is not required under 112, and indeed, such recitation is disfavored: 'Indeed, the forced recitation of known sequences in patent disclosures would only add unnecessary bulk to the specification. Accordingly we hold that where, as in this case, accessible literature sources clearly provided, as of the relevant date, [claimed structure], satisfaction of the written description requirement does not require either the recitation or incorporation by reference.')

For these reasons and the reasons given in the prior responses and the Appeal Brief, the entirety of which is incorporated hereby and not repeated here, Applicants traverse and respectfully request reconsideration and withdrawal of the rejections.

Claims 34 and 36 are rejected under 35 U.S.C. §112 first paragraph as allegedly lacking written description. In the "Response to Argument" beginning at page 25 of the Answer, the Examiner alleges that the recitation of "200 psi" lacks written description support. The Examiner repeats his prior arguments and then newly adds for the first time that the limitation "at least" has no upper limit and reads on embodiments outside of CA 841,938. As an ordinarily skilled artisan would understand, the recitation "at least 200 psi" not describing a range or an option, it is describing a structural property common to hydroentangling fabrics.

The incorporated references and evidence expressly state this, for the reasons given in the prior responses and the Appeal Brief, the entirety of which is incorporated hereby, this is common knowledge to the ordinarily skilled artisan. Thus the assertion that there is no written description support for such a recitation is clear error, and represents a fundamental misapplication of the law of written description for the reasons already given.

For these reasons and the reasons given in the prior responses and the Appeal Brief, the entirety of which is incorporated hereby and not repeated here, Applicants traverse and respectfully request reconsideration and withdrawal of the rejections.

III. CLAIMS 1-2, 4, 6-8, 13, 23, 25-27, AND 31-36 PATENTABLE UNDER 35 U.S.C. §112, SECOND PARAGRAPH AS THE CLAIMS ARE NOT INDEFINITE

Claims 1-2, 4, 6-8, 13, 23, 25-27, and 31-36 are rejected under 35 U.S.C. §112, second paragraph for allegedly being indefinite. Independent claims 1 and 23 each recite: "**a hydroentangling support fabric having the mechanical properties and structural strength to reflect liquid jetted from the hydroentangling apparatus**." The Examiner rejects claims 33 and 35 for being in a Markush format, citing the reference to properties where the flat filament is not present. For the reasons and the reasons given in the prior responses and the Appeal Brief, the entirety of which is incorporated hereby and not repeated here, Applicants traverse and respectfully request reconsideration and withdrawal of the rejections.

At pages 26-27 of the Answer, the Examiner severally attempts to argue by an extended analogy to a claim for a car, which is irrelevant. Applicants do not argue the merits of a hypothetical claim or address rhetorical questions. The claim recites, very specifically, that the fabric have: "the mechanical properties and structural strength to **reflect liquid jetted from a hydroentangling apparatus**." This is a threshold property of all such hydroentangling support

fabrics, and a clearly recited one at that. If they lack this, then they are not hydroentangling support fabrics. The mere fact that one could claim specific variables does not render the claims indefinite.

For these reasons and the reasons given in the prior responses and the Appeal Brief, the entirety of which is incorporated hereby and not repeated here, Applicants traverse and respectfully request reconsideration and withdrawal of the rejections.

IV. THE CLAIMS ARE PATENTABLE UNDER 35 U.S.C. §103 OVER ELSENER IN VIEW OF ANY ONE OF SCHWARTZ OR WHIGHT

Claims 23, 25-27, 31 and 35-36 were rejected under 35 USC § 103 (a) over Elsener in view of any one of Schwartz, or Whight. For the reasons and the reasons given in the prior responses and the Appeal Brief, the entirety of which is incorporated hereby and not repeated here, Applicants traverse and respectfully request reconsideration and withdrawal of the rejections.

V. THE CLAIMS ARE PATENTABLE UNDER 35 U.S.C. §112 OVER NOELLE

Claims 1-2, 4, 6, 13, 23, 25-27, 31, and 33-36 are rejected under §102 or §103 over Noelle. Claims 1-2, 4, 6, 13, 23, 25-27, 31, and 33-36 are rejected under §102 or §103 over Noelle. The claims recite: "**a hydroentangling support fabric** having the mechanical properties and structural strength to reflect liquid jetted from the hydroentangling apparatus and comprising flat filaments, wherein said **support fabric is in a continuous loop or made endless**." As Applicants explained in detail in the Brief, citing the specification as well as the evidence and Figures of the references themselves, these terms have a specific meaning that excludes Noelle's fabric on a drum. For the reasons and the reasons given in the prior responses and the Appeal Brief, the entirety of which is incorporated hereby and not repeated here, Applicants traverse and respectfully request reconsideration and withdrawal of the rejections.

Claims 1-2, 4, 6, 13, 23, 25-27, 31, and 33-36 are rejected under §102 or §103 over Noelle. The claims recite: "a **hydroentangling support fabric** having the mechanical properties and structural strength to reflect liquid jetted from the hydroentangling apparatus and comprising flat filaments, **wherein said support fabric is in a continuous loop or made endless for an industrial belt**." As Applicants explained in detail in the Brief, citing the specification as well as the evidence and Figures of the references themselves, these terms have a specific meaning that excludes Noelle's fabric on a drum.

A drum is different from a hydroentangling support fabric, which is an industrial belt. Applicants have amended the claim to father clarify this point, although such amendment is purely clarifying in nature and in no way alters the scope of the claim. The following reference criticizes conflating drum-based hydroentangling with that of using a forming fabric:

> **The Methodology and the Analysis**
>
> The description of the hydroentangling set up is vague and unclear. It is stated that the fabric was passed through the Fleissner unit twice on one side and twice on the other side. It is not clear if the unit has only one manifold, or more **and it is not clear whether the hydroentangling unit uses belt or drum for hydroentangling. The choice of the hydroentangling surface critically impacts the degree to which the fibers can be split or fibrillated.**

Comments on the Paper Entitled "Splitting of Islands-in-the-Sea Fibers (PA6/COPET) During Hydroentangling of Nonwovens" http://www.jeffjournal.org/papers/Volume3/LettertoEditor.pdf

Thus the reference shows that drums and belts are not interchangeable, much less a sleeve for a drum. To explain, a sleeve for a drum cannot be used as a hydroentangling belt.

First, in a hydroentangling support fabrics, flattened filaments have the flat cross-sectional profile along the entire length. The flat filaments can be formed thus by extrusion or by calendering. If calendered, one or both surfaces can take on the "flattened" shape, and the yarn no longer will be round. This will be somewhat "discontinuous" due at yarn knuckles, but in a fabric the effect will nonetheless be continuous, and not localized for "embossing in a pattern" as taught in the Noelle.

The presence of these flat cross-sectional shaped yarns fabric belt cause "reflection" of the applied water stream energy from that surface and back up towards and through the nonwoven being entangled. This is distinct from Noelle, in which claims are related to texturing or patterning the nonwoven using the cylinder on which this wire sleeve is installed, not hydroentangling proper.

With respect to a comparison to Noelle's sleeve, a hydroentangling fabric first of all must be a belt. It must be stable in both the MD and CD directions; it must be abrasion resistant as it passes over any stationary elements (eg vacuum sources/boxes; see the incorporated '943 patent); must support the nonwoven fabric being manufactured without bending/ deflecting; and must act as the power transmission belt for the entire device.

Noelle's sleeve does none of this. See Noelle at paragraphs [0032], [0034], and [0061-0063]. Noelle's sleeve is fixed upon a rotating support element – the drum. Therefore MD and CD stability are mechanically set; there are no stationary elements to pass over; it cannot deflect or bend due to the honeycomb drum support structure, and does not act in any way as a power transmission device.

Furthermore, the drums as noted have an internal vacuum source to suck in the water from the jets, to "pull" the nonwoven into the sleeve or drum surface to get some texture in the nonwoven, and to insure the water jets penetrate through the nonwoven. There are no teachings whatsoever about desiring reflective water flow in the opposite direction.

While at paragraph [0092] of Noelle it mentions a structure with rectangular shaped warp yarns, but cites no reasons or advantages as to why. With the internal vacuum source, indeed it cannot even be determined if the flat yarns would work as intended as a sleeve on a drum. Thus there is no nexus between the use of flat filament in Noelle and any advantage therefrom, much less one in the different structure of a hydroentangling support fabric.

At pages 28-29 of the Answer the Examiner, rather than addressing the distinctions raised in the Appeal Brief, again makes an irrelevant analogy to a car, which demonstrates he is not considering the way ordinarily skilled artisans would understand the terms. Again, the broadest reasonable construction rubric standard, "...does not give the PTO an unfettered license to interpret claims to embrace anything remotely related to the claimed invention. Rather, claims should always be read in light of the specification and teachings in the underlying patent." *In re Suitco Surface* (CAFC 2009-1418) (Decided April 14, 2010). The specification shows that an ordinarily skilled artisan would simply not read **hydroentangling support fabric... wherein said support fabric is in a continuous loop or made endless"** to cover a covering for a cylinder. Indeed, the term "hydroentangling support fabric" is understood to be a belt. Thus the Examiner fails to articulate a *prima facie* case with respect to this element, and the burden has not yet shifted Applicants.

Regarding unexpected results, the Examiner states Applicants have provided no proof. While Applicants urge the Examiner has not properly made out *prima facie* case to neccecitate such a showing, Applicants have provided unrebutted evidence. The Examiner's rationale for obviousness rests entirely on allegations that the claims merely recite and intended use, and that all the properties claimed and proffered are inherent in Noelle's sleeve. The Examiner has not given any other reason, evidence, or rationale as to why an ordinarily skilled artisan would use Noelle's sleeve a hydroentangling support fabric.

Facts established by rebuttal evidence must be evaluated along with the facts on which the conclusion of a *prima facie* case was reached, not against the conclusion itself. *In re Eli Lilly*, 902 F.2d 943, 14 USPQ2d 1741 (Fed. Cir. 1990) (See MPEP 716.01(d). The Examiner's case was reached on the basis of inherency. The specification states at paragraph 0014 of the publication: "[t]he inventors of the present invention have recognized that implementing a hydroentangling process on a fabric which incorporates flat filaments improves the resulting products." Because the advantages recited and evidenced are specific to hydroentangling support fabrics, for the reasons given, there is no reason to expect such advantages from different fabrics such as Noelle's sleeve as implemented on a drum. Moreover, the showings are proved in the specification, as discussed throughout prosecution and during interviews with the Examiner in which Applicants were encouraged to cite to exactly this evidence. Indeed, it was at their urging that Applicants cited extensively to pages 5-8, and closed with:

> The advantages of hydroentangling according to the invention are confirmed using modified versions of the fabric of Figures 4A and 4B on a machine incorporating the structure of Figure 8. **In particular, the invention reduces entangling of fibers to the fabric surface and improves reflection (or "flashback") of water jets.** Furthermore, the invention **improves release of the fiber web from the hydroentangling fabric after entangling and improves MD/CD tensile ratios.** More specifically, tests using a machine in accordance with Figure 8 have shown that release of the fiber web from the hydroentangling fabric improves such that the draw is reduced from about 8% to 0%, and that the MD/CD ratio improvement is about 10% to 40%.

Nothing in the art or any rationale the Examiner has given shows that a flat filament was contemplated for a hydroentangling support fabric. Thus, *a priori*, no ordinarily skilled artisan could expect "reduced entangling of fibers to the fabric surface" or "improve[d] reflection (or "flashback") of water jets," or "improve[d] release of the fiber web from the hydroentangling fabric after entangling" or "improves MD/CD tensile ratios." Indeed, there is nothing "expected" about the "release of the fiber web from the hydroentangling fabric improves such that the draw is reduced from about 8% to 0%, and that the MD/CD ratio improvement is about 10% to 40%."

Thus, with all due respect, it is not fair that the Examiner states for the first time in the Answer, referring to FIGS. 1 and 2: "This result isn't even unexpected to one of no skill in any

art." The Examiner gives no reasoned basis for this statement. The reduced thickness of the weave was another of the many advantages which flowed from the inventor's recognition that flat filaments in a hydroentangling support fabric improves nonwoven products. If the Examiner has some evidence or scientific reasoning to establish the reasonableness of the examiner's belief that "[t] his result isn't even unexpected to one of no skill in any art," Applicant respectfully urges the Examiner provide it. This is especially the case where the Examiner relies exclusively on inherency and allegations of reciting intended use. "[T]he examiner must provide some evidence or scientific reasoning to establish the reasonableness of the examiner's belief that the functional limitation is an inherent characteristic of the prior art" before the burden is shifted to the applicant to disprove the inherency.). *Ex Parte Whalen II*, Appeal 2007-4423, July 23, 2008 (internal citations omitted).

Also, the statement ignores all the other advantages of flat filaments in a hydroentangling support fabric improves nonwoven products, laid out above and throughout prosecution. The Examiner must weigh **all** the evidence of unexpected results in making the patentability determination. "The ultimate determination of patentability must be based on consideration of the entire record, by a preponderance of evidence, with due consideration to the persuasiveness of any arguments and any secondary evidence." *In re Oetiker*, 977 F.2d 1443, 24 USPQ2d 1443 (Fed. Cir. 1992). If the preponderance of the evidence shows results that could not be expected from the alleged prima facie case, then the claims are patentable. Thus if the Examiner believes the reduced thickness of the hydroentangling support fabric "isn't even unexpected to one of no skill in any art," then the Examiner must give his evidence or rationale why this is so, and why he gives this conclusion more significance more weight than all the other unexpected results and advantages.

For these reasons and the reasons given in the prior responses and the Appeal Brief, the entirety of which is incorporated hereby and not repeated here, Applicants traverse and respectfully request reconsideration and withdrawal of the rejections.

VI. THE CLAIMS ARE PATENTABLE OVER GASSIER

The Examiner rejects claims 23, 25-27, 31-32, 35 and 36 under §102, or in the alternative, under §103, over Gassier. These arguments were inadvertently omitted from the Appeal Brief, and are represented here.

Claim 23 recites:

> An improved hydroentangling support fabric in a hydroentangling apparatus for production of a hydroentangled nonwoven product, the improvement comprising:
>
> said hydroentangling support fabric in the hydroentangling apparatus having the mechanical properties and structural strength to reflect liquid jetted from the hydroentangling apparatus and comprising flat filaments having a flat cross-sectional shape, wherein said support fabric is in a continuous loop or made endless for an industrial belt.

The claim requires: An improved hydroentangling support fabric in a hydroentangling apparatus …said hydroentangling support fabric in the hydroentangling apparatus." As discussed throughout the prosecution history, Gassier discloses a dryer fabric for a papermaking machine. Thus at no point does Gassier disclose a hydroentangling support fabric in a hydroentangling apparatus. As Gassier lacks a recited feature of the claim, the reference fails to support a prima facie case under 102.

As for 103, first, as amply laid out in the prior responses, a dryer fabric for a papermaking machine has different structure than a hydorentangling fabric. This is shown not only by Gassier, but by the references with which the Office Action has attempted to combine Gassier throughout prosecution.

Moreover, the inclusion of "said hydroentangling support fabric in the hydroentangling apparatus" in the body of the claim from the preamble was done in part to clarify that the claimed fabric is indeed a hydroentangling support fabric, and also as the Office Action indicated during a previous interview that such a recitation would bring the claim more in line with claim 1, which the in the prior interview in this case the Office Action and Supervisory Office Action suggested that if Applicants could cite evidence as to the advantages of the claimed flat filaments in hydroentangling support fabrics, Applicants would be "headed in the right direction."

The Office Action has not addressed this evidence, but has merely charged inherency, despite these showings. Applicants will respectfully urge that Applicants have more than rebutted the charge that dryer fabrics necessarily and inherently have the same structure as hydroentangling fabrics.

To reiterate, for evidentiary support of the unexpected advantages of the claimed flat filaments in hydroentangling support fabrics, Applicants refer to the quoted specification from

the prior response, which shows the many advantages of flat filaments in hydroentangling support fabrics over hydroentangling support fabrics without this structure, including:

- a weave thickness T' that is smaller than the thickness T, wherein T represents a thickness without said flat filaments;
- a weave of more resistant to water flow in a direction perpendicular or substantially perpendicular to the plane in which a plurality of CD monofilaments lie;
- structure that reduces entangling of fibers to the fabric surface;
- improved MD/CD tensile ratios as compared to a fabric without said flat filaments; and
- improved release of the fiber web from the hydroentangling fabric after entangling.

As discussed during the prior interview and in the prior responses, in view of the many superior properties achieved by the flat filaments as compared to hydroentangling support fabrics without the flat filaments as evidenced by the specification, Applicants urge that this is an ample demonstration of the unexpected results of the claimed hydroentangling support fabric including flat filaments. See MPEP 716.02(a).

In response to this evidence, at page 24, the Office Action simply states that there is no structural between the claims, treating the recitation of a hydroentangling apparatus as "an intended use." This is in error, as the claims require the hydroentangling apparatus. Thus the 102 rejection must fail on this basis.

The Office Action also states that Applicants argued, "Gassier fails to teach or suggest the claimed fabric because the fabric is not in the location currently claimed (in a hydroentangling apparatus). The Office Action's characterization of Applicants remarks is not well-taken.

Applicants have submitted extensive evidence as to the differences between hydroentangling support fabrics and apparatuses and dryer fabrics in papermaking, clearly demonstrating that they are not "substantially identical." Applicants have also detailed the unexpected advantages flat filaments add to the hydroentangling process, which has nothing to do with dryer fabrics. The Office Action has never addressed these showings in any substantive fashion, but instead has merely reasserted the improper "inherency" and "intended use" arguments.

At page 7, the Office Action also inexplicably refers to "product-by-process" claims. Flat filaments are structures, not a process. A hydroentangling apparatus is an apparatus, not a process.

For these reasons, the rejection over Gassier fails under §§ 102 and 103. Applicants thereby request reconsideration and withdrawal of the rejections on this basis.

VII. THE CLAIMS ARE PATENTABLE OVER ZLATKUS

Claims 1-2, 4, 6, 13, 23, 25-27, 31, and 33-36 are rejected under §102 or §103 over Zlatkus. For the reasons and the reasons given in the prior responses and the Appeal Brief, the entirety of which is incorporated hereby and not repeated here, Applicants traverse and respectfully request reconsideration and withdrawal of the rejections. Zlatkus has no disclosure of flat filaments. As Applicants showed in detail in the prior response and Appeal Brief, and as the Zlatkus's Figures show, the flatness and the knuckle sizes are not **a function of the shape of the wire filament itself**, but rather, how the mesh of the wire is formed.

Applicants have amended the claims to recite "a flat cross-sectional shape" and reassert these arguments.

The Examiner also makes an argument that because Zlatkus's flat knuckle wire is not called a small knuckle wire, the filaments of Zlatkus's wire are inherently flat. Applicants submit as an objective reference "An Examination of the Hydroentangling Process Variables" which shows that ordinarily skilled artisans use the term "wire" to refer to the entire forming fabric, and not the filaments that make it up: "Low speed hydroentangling data for nylon 66, polyethylene terephthalate (PET), polypropylene terephthalate (PTT), and polypropylene (PP) fibers using **very different forming wires** indicate that force acting on the fiber, not energy, is the important variable." "*Figure 5* is a photograph of the fibers **on a coarse wire** after hydroentanglement illustrating the role of the fabric knuckles in forming the fabric texture.' *An Examination of the Hydroentangling Process Variables*, found at http://www.jeffjournal.org/INJ/inj05_1/p25-33.pdf, Abstract, page 25, Spring 2005.

For these reasons and the reasons given in the prior responses and the Appeal Brief, the entirety of which is incorporated hereby and not repeated here, Applicants traverse and respectfully request reconsideration and withdrawal of the rejections.

VIII. THE CLAIMS ARE PATENTABLE OVER GASSIER IN VIEW OF STRANDQVIST

Claims 1-2, 4, 6, 13, 23, 25-27, 31, and 33-36 are rejected under 35 U.S.C. §103 over Gassier in view of Strandqvist. For the reasons and the reasons given in the prior responses and the Appeal Brief, the entirety of which is incorporated hereby and not repeated here, Applicants traverse and respectfully request reconsideration and withdrawal of the rejections.

The Examiner newly proffers an "obvious to try" argument, alleging the rationale is "a desire to construct a functioning hydroentangling apparatus." As the Examiner notes, when there is a design need or market pressure to solve a problem and there are a finite number of identified, predictable solutions, a person of ordinary skill has good reason to pursue the known options within his or her technical grasp. *KSR v. Teleflex.* The Examiner fails to identifies a design need or market pressure to solve any problem with respect to hydroentangling forming fabrics. There was, at the time of filing the present application, no preexisting problem with the "functioning of hydroentangling apparatuses." Absent providing such a reason or indentifying such a problem, then by definition there are no "identified, predicable solutions." Thus the Examiner fails to explain why an ordinarily skilled artisan would find it "obvious to try" to use flat filaments "motivated by a desire to construct a functioning hydroentangling apparatus." Thus again the Examiner fails to establish *a prima facie* case.

Moreover, even if the Examiner's "obvious to try" rationale supported a *prima facie* case, it is one that is amply rebutted by the evidence of record. Facts established by rebuttal evidence must be evaluated along with the facts on which the conclusion of a *prima facie* case was reached, not against the conclusion itself. *In re Eli Lilly*, 902 F.2d 943, 14 USPQ2d 1741 (Fed. Cir. 1990) (See MPEP 716.01(d). The Examiner's case was reached on the basis of "obvious to try" in order "to construct a functioning hydroentangling apparatus." For the reasons given with respect to the Noelle rejection above, because the advantages recited and evidenced are specific to hydroentangling support fabrics, for the reasons given, there is no reason to expect such advantages from different fabrics such as Gassier's dryer fabric and Strandqvist's press felt.

The Examiner also fails to give any rationale why an ordinarily skilled artisans would find it obvious to use a dryer fabric as a hydroentangling support fabric.

For these reasons and the reasons given in the prior responses and the Appeal Brief, the entirety of which is incorporated hereby and not repeated here, Applicants traverse and respectfully request reconsideration and withdrawal of the rejections.

IX. THE CLAIMS ARE PATENTABLE OVER GREENWAY IN VIEW OF EITHER NOELLE, ZLATKUS OR FAGERHOLM

Claims 1-2, 4, 6, 13, 23, 25-27, 31, and 33-36 are rejected under §103 over Greenway in view of any one of Noelle, Zlatkus or Fagerholm. For the reasons and the reasons given in the prior responses and the Appeal Brief, the entirety of which is incorporated hereby and not repeated here, Applicants traverse and respectfully request reconsideration and withdrawal of the rejections.

X. THE CLAIMS ARE PATENTABLE OVER STRANDQVIST IN VIEW OF LEWIS

Claims 1-2, 4, 6, 13, 23, 25-27, 31, and 33-36 are rejected under 103 over Strandqvist in view of Lewis. For the reasons and the reasons given in the prior responses and the Appeal Brief, the entirety of which is incorporated hereby and not repeated here, Applicants traverse and respectfully request reconsideration and withdrawal of the rejections.

In the Answer the Examiner merely repeats the arguments regarding unexpected results made in the other rejections above; hence Applicant's remarks above apply equally thereto. For these reasons and the reasons given in the prior responses and the Appeal Brief, the entirety of which is incorporated hereby and not repeated here, Applicants traverse and respectfully request reconsideration and withdrawal of the rejections.

XI. DEPENDENT CLAIMS

Nothing in the cited art of record cures the deficiencies of the art as applied to independent claims 1 and 23. For the sake of more organized presentation of the issues, certain of the dependent claims are addressed under the headings given rejections in the Appeal Brief, incorporated by reference hereby. Save for claims 33-36 where argued separately above under such rejections as articulated above, the dependent claims stand or fall with independent claims 1 and 23. Appellants thereby respectfully request reversal of the rejections and allowance of the claims.

CONCLUSION

In view of the foregoing amendments and remarks, all of the claims in this application are patentable over the prior art, and early and favorable consideration thereof is solicited.

In the event that the Examiner disagrees with any of the foregoing comments concerning the disclosures in the cited prior art, it is requested that the Examiner indicate where in the reference, there is the basis for a contrary view.

Please charge any fees incurred by reason of this response and not paid herewith to Deposit Account No. 50-0320.

If any issues remain, or if the Examiner has any further suggestions, the Examiner is invited to call the undersigned at the telephone number provided below. The Examiner's consideration of this matter is gratefully acknowledged.

Respectfully submitted,
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APPENDIX

EXHIBIT A

Comments on the Paper Entitled "Splitting of Islands-in-the-Sea Fibers (PA6/COPET) During Hydroentangling of Nonwovens"

Behnam Pourdeyhimi, Ph.D.

North Carolina State University, Raleigh, North Carolina, USA

The Journal of Engineered Fibers and Fabrics (JEFF) is gaining wide recognition in the global R&D community. However, this paper appears to fall short of your normal publishing standards. The data presented is unfortunately technically incomplete and inaccurate, plus the background literature omits some important publications and other ongoing research in this area.

Various sections are dealt with separately below:

Misleading title

To use the term "splitting" is inaccurate and incorrect for fibers such as islands in the sea. Split refers to "dividing" or "breaking-up". A more appropriate term would be fibrillate or fracture. This is indeed why the title of several patents held by NC State filed over the last 5 years refers to fibrillating bicomponent fibers such as islands in the sea and other cross sections.

Splittable fibers are known in the art to refer to those bicomponent fibers that have one single common interface and where the two components are also exposed to air on the surface of the fibers. Classical examples are: segmented pie, segmented ribbon, side-by-side and tipped trilobal where the tips do not wrap the fiber to form a sheath.

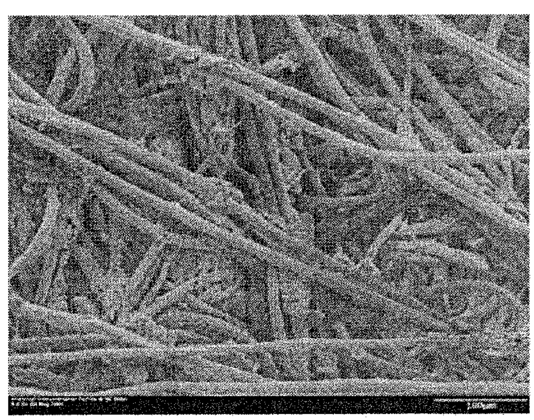
Literature Review

Even without the above distinction, there is a significant body of literature that deals with splittable fibers, and bicomponent where the sea or one component is removed. Most notably, the literature dealing with Evolon (Freudenberg) is totally ignored in the literature review. Evolon is the first splittable spunbond fabric commercially available for many years. The paper also cites only one of the published patents held by NC State and chooses to ignore two other key published patents that are relevant to the subject at hand. The paper states that:

"Finally, Behnam Pourdeyhimi, et. al. [23] utilized hydro-energy (hydroentanglement process) for fibrillating a set of bicomponent fibers. From their invention, they discovered that islands-in-sea fibers can be made to split by hydroentangling without dissolution if the sea polymer is sufficiently weak and particularly when the two components have little or no affinity for one another."

The significance of the difference between splittables and fibrillatable fibers was not recognized. In splittables, it is the interface between the two components that controls splittablity. In islands in the sea (I/S) structures, it is the interface together with the ability of the waterjet to break apart or fibrillate the sea from the island. Consequently, often higher levels of energy (hydroentangling) are required to break apart a fiber than to split one single interface depending on the polymers used in the two phases.

Below, we show a picture of a sheath-core structure where the sheath is fractured and fibrillated (not split). Clearly, it is the choice of the polymers that allows one to even fracture the sheath. This structure was not subjected to any thermal treatment and the break up of the sheath is primarily due to mechanical stress.



These are fully discussed in a number of worldwide patents filed by NC State. Several are published and several will publish soon. Some key published patents are:

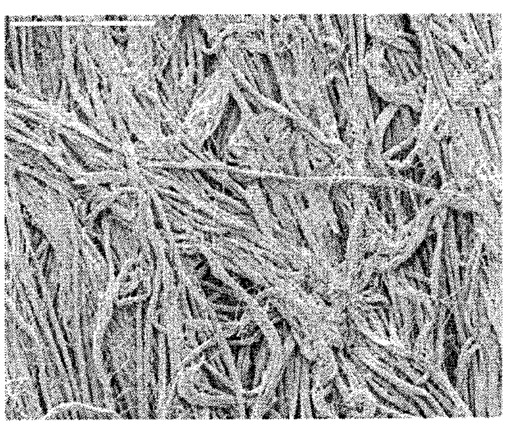
1. B. Pourdeyhimi, N. Fedorova and S. Sharp, Lightweight high-tensile, high-tear strength bicomponent nonwoven fabrics, US Patent Application 20060223405, October 5, 2006.

2. B. Pourdeyhimi, N. Fedorova and S. Sharp, High strength, durable micro & nano-fiber fabrics produced by fibrillating bicomponent islands in the sea fibers, US Patent Application 20060292355, December 28, 2006.

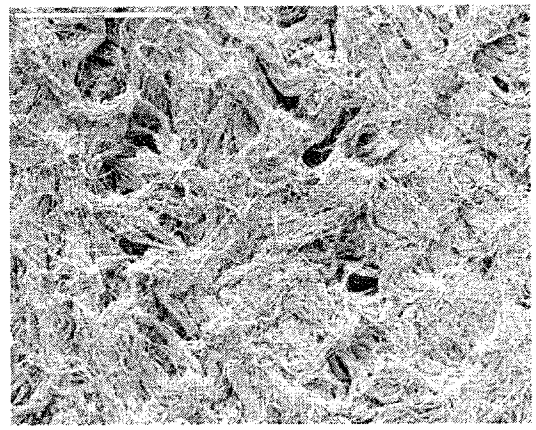
3. B. Pourdeyhimi and S. Sharp, High Strength, Durable Fabrics Produced By Fibrillating Multilobal Fibers, US Patent Application 20080003912, January 3, 2008.

Additional patents will be published soon.

Below, we also show the onset of what we call fibrillation. At low levels of hydroentangling energy, the fibers on the surface only start to fibrillate. Therefore, to achieve bonding and fracturing in one step, requires sequential increases in waterjet pressure – another critical issue not addressed by the paper.



The following picture shows an example of a fully fibrillated I/S where there are 108 nylon islands in a sea of polyethylene. The same can be achieved by using other polymer systems such as nylon and polyester or polyester and polyethylene.



Note that the small apertures seen in the fabric are due to the interaction with the surface used on the hydroentangling drum. The waterjet-fiber-surface interactions control to a great extent the degree of fracture or splitting. This topic will be discussed in a future paper.

The Methodology and the Analysis

The description of the hydroentangling set up is vague and unclear. It is stated that the fabric was passed through the Fleissner unit twice on one side and twice on the other side. It is not clear if the unit has only one manifold, or more and it is not clear whether the hydroentangling unit uses belt or drum for hydroentangling. The choice of the hydroentangling surface critically impacts the degree to which the fibers can be split or fibrillated.

The basis weight of the fabric was also not described. What is mentioned is that 2 grams of fibers were opened by hand and then hydroentangled. Therefore, it appears that no carded webs were produced and that the webs were produced by hand. If this was the case, then how would one determine mechanical properties of the final product given that we have no way of controlling the fiber orientation or the uniformity in the web? How was a web large enough produced to allow the tensile samples to be prepared? To open bundles of fibers by hand will lead to tremendous operator dependencies and non-uniformities that will determine the ultimate properties of the fabric. It is also not clear how sufficiently large samples were

developed for testing purposes? And what the final basis weight of the samples was.

The analysis of "splittability" leaves much to be desired. Fibers do not split evenly across the width. If one analyzes splittability, it will be seen that the fibers split differently on the top and in the ridges of jet streaks. Additionally, fibers split differently on the surface and in the bulk. Soon, there will appear a paper by Shim, *et. al.* that will discuss appropriate methodologies for determining splittability. To fully and reliably analyze splittability requires 3D sectioning and imaging of the structure over a relatively large area that encompasses several jet spacing. Shim's paper will introduce the concept of using Digital Volumetric Imaging (DVI) for determining splittability.

The tensile data are plotted versus jet pressure. This graph is also technically incorrect and incomplete since we do not know the number of manifolds or the basis weight of the samples. The data should be plotted versus hydroentangling energy. This requires however, the basis weight and the number of manifolds to be specified.

The hydroentangling energy calculation is based on Bernoulli equation that ignores viscous losses throughout the system. Having the manifold's pressure, P_1, the jet velocity is:

$$V_1 = \sqrt{2P_1 / \rho}$$

Where $\rho = 998.2 \text{kg/m}^3$ is the density of water at room temperature, P_1 is the pressure in Pa, and V_1 is in m/s. Note that 1 bar is equal to 10^5 Pa.

The rate of energy transferred by waterjet is calculated as follows:

$$\dot{E} = \frac{\pi}{8}\rho d^2 C_d V^3$$

where d is diameter of the orifice capillary section in meter (0.127 mm in the system used), C_d is the discharge coefficient, and $\dot{E}$ is energy rate in J/s.

Specific energy is calculated based on the following formula:

$$SE[\frac{J}{kg_{fabric}}] = \frac{\dot{E}}{\dot{M}}$$

where $\dot{M}$ is the mass flow rate of the fabric in Kg/s and is calculated as follows:

$$\dot{M} = \text{Samplewidth[m]} \times \text{Basisweight[kg/m}^2\text{]} \times \text{Beltspeed[m/s]}$$

Therefore, *SE* will be obtained in *Joules per kg of fabric*. This can also be expresses as *Watts per kg of fabric.*

Typically, as the energy increases, the tensile properties increase up to a point and then begin to decline somewhat. The tear properties are more sensitive to bonding and quickly decline after the structure has been consolidated. The data for tensile properties are impossible to interpret and given that the webs were made by hand, the data are not scalable to carded systems.

The authors make several remarks about the sea and the matrix and state that:

"For the case of these modified islands-in-the-sea fibers, the walls of the sea between the islands appear to be very thin and perhaps weak, while the islands solidifying and crystallizing within the matrix during processing become stronger. Therefore with implementation of high mechanical forces on these modified island-in-the-sea fibers, the sea components damaged easily and remain in contact with islands. Furthermore it can be seen in Figure 6 that the fibers split shows small dots or attachments which may be the presence of co-polyester particles on the surface of split fibers..."

This statement is pure conjecture and the authors are referred to the articles shown below:

1. N. Fedorova and B. Pourdeyhimi, High Strength nylon Micro- and Nanofiber Based Nonwovens Via Spunbonding, Journal of Applied Polymer Science, 104 (5): 3434-3442, (2007).

2. N. Fedorova, S. Verenich and B. Pourdeyhimi, Strength Optimization in Point-bonded Nonwovens, Journal of Engineered Fibers and Fabrics, Volume 2, Issue 1, (2007).

These papers clearly discuss and distinguish the role of solidification in controlling the properties of the island fibers. Similarly, the classical works of Kikutani in Japan need to be studied where he discusses the concept of "super-draw" in bicomponent fiber formation. The choice of the polymer systems together with processing conditions can indeed lead to highly oriented islands and highly amorphous sea to facilitate fibrillation.

What the NC State group has shown and is documented in the worldwide patent filings is that islands in the sea and other fiber configurations can be fibrillated at speeds much higher than 2 meters per minute (used in this paper). These include combinations of nylons and polyesters and polyesters (or co-polyesters) and polyolefins and similarly nylons and polyolefins. The polyester nylon combinations as a rule of thumb require higher levels of hydroentangling energy for fibrillation. Some of the most unique structures produced are polyester sea and nylon islands, nylon or polyester islands and polyethylene sea. In all cases however, the tensile and tear strength of these structures are superior to those of other splittables (segmented pie, for example) and much higher than the ones reported in this paper. Note that the titles of the patent filings often refer to "high strength" structures, a unique character of fibrillated bicomponents.

Based on our continuing project work, we will shortly prepare and submit a series of papers to address the issues and the pros and cons of fibrillation versus splitting of classical splittable fibers. Significant contributions are also being made in Europe and Asia. It is our hope that this Letter to the Editor will spark further rigorous discussion and more global interaction within the research community.

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Editor: We cordially invite you to share your technical insights on this and other areas of R&D. Please submit your comments, suggested additions and letters to the editor at http://jeff.edmgr.com. Please be sure to provide us with your name and contact information.

EXHIBIT B

An Examination of the Hydroentangling Process Variables

By A. M. Seyam, and D. A. Shiffler, College of Textiles, North Carolina State University, Raleigh NC; and H. Zheng, Goulston Technologies, Monroe, NC

Abstract

Fabric response to hydroentangling process variables is usually presented as a plot of energy consumed / kg of fabric produced. This paper presents a simple mechanical model describing the transformation of a random fiber web into a hydroentangled fabric having a clearly defined cellular structure dependent on the forming wire. The model indicates that only a tiny fraction of the energy supplied by the entangling jets is consumed in the production of the fabric. Low speed hydroentangling data for nylon 66, polyethylene terephthalate (PET), polypropylene terephthalate (PTT), and polypropylene (PP) fibers using very different forming wires indicate that force acting on the fiber, not energy, is the important variable.

Key Words

hydroentanglement, water jet needling, spunlacing, hydraulic needling, hydroentangling process, specific energy, hydroentangling forces, hydroentangling mechanical model.

INTRODUCTION

Hydroentanglement is perhaps the fastest growing bonding method in the nonwoven arena, and the identification of critical variables in the transformation of a web having relatively unorganized fiber geometry to one with a clearly defined cellular structure is of considerable technical interest. Traditionally experiments usually determined the effect of fabric speed and jet pressure when fabric is passed through a given machine with a single forming wire. In such an experiment, energy per unit fabric weight appears to be the dominant variable and figures such as *Figure 1*[1,2,3,4,5,6] are common.

This work views hydroentanglement as a process in which a sheet of randomly oriented fibers is transformed into one with a definite cellular structure imparted by fiber flow around the knuckles of a forming wire. This process is depicted schematically in *Figure 2*. While this structure is quite apparent to the naked eye for coarse mesh wires, it is also present in very fine meshes under magnification as illustrated in *Figures 3 and 4*..

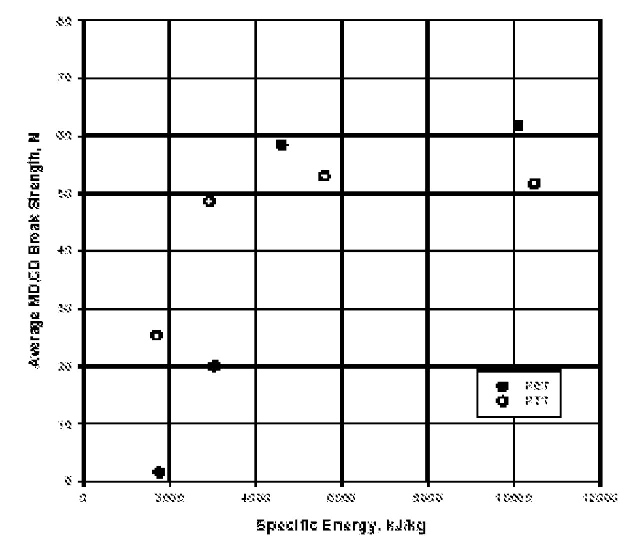

Figure 1
EFFECT OF SPECIFIC ENERGY ON HYDROENTANGLED FABRIC TENSILE STRENGTH FOR 100 MESH FORMING WIRE

Figure 5 is a photograph of the fibers on a coarse wire after hydroentanglement illustrating the role of the fabric knuckles in forming the fabric texture. Note that the fibers are pushed off the crests of the knuckles into the open inter weave spaces and the open cells are formed at the knuckle, not the open

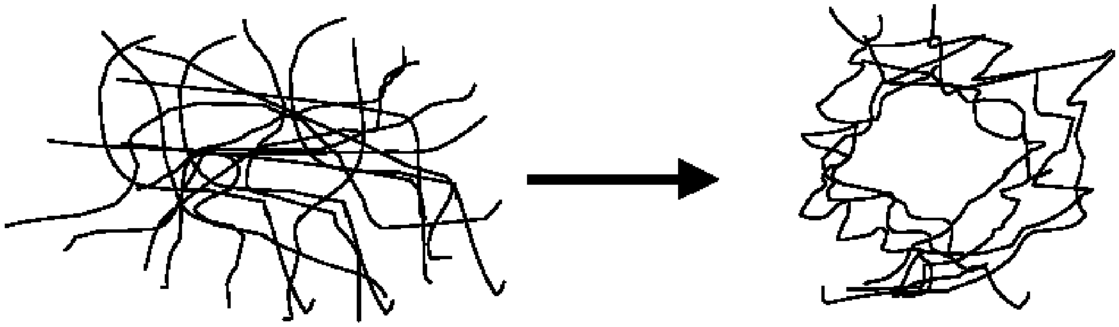

Figure 2
FIBER TRANSFORMATION DURING HYDROENTANGLEMENT

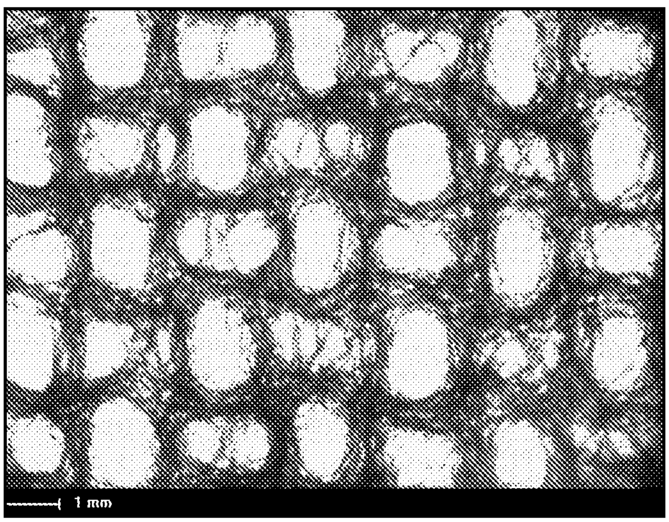

Figure 3
FABRIC TEXTURE DEVELOPED ON 10 MESH SCREEN (3.45 MPA)

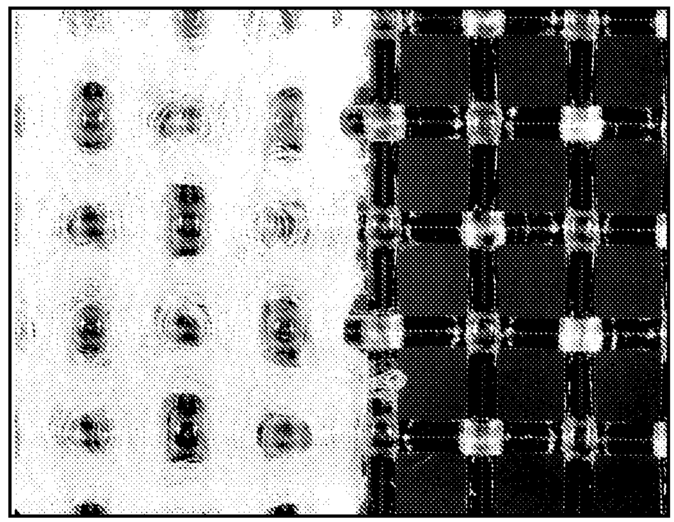

Figure 5
WIRE / FABRIC INTERACTION DURING HYDROENTANGLEMENT(7)

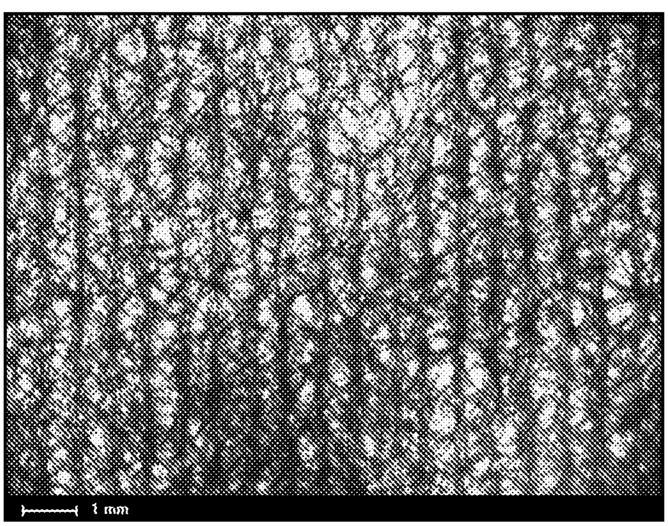

Figure 4
FABRIC TEXTURE DEVELOPED ON 100 MESH SCREEN (3.45 MPA)

spaces.

The objective of this work was to understand the influence of fiber properties, forming wire, and jet pressure on the fabric tensile properties resulting from the hydroentangled fabric cellular structure. Fabric tensile properties were used as a marker for fabric texture development.

EXPERIMENTAL DESIGN

Details of the experimental design may be found in (8) and publications currently in preparation. The dependent variable reported here is fabric tensile break strength which proved to be a logical marker for development of such properties as break elongation and tear. Independent variables in the trials were:

- Jet pressure
- Forming wire
- Fiber content
- Number of jet strip passes.

A detailed discussion of these variables in included in (8). The major strengths of the study were the wide range of screen types summarized in *Table 1*, and variety of fibers summarized in *Table 2.*

The major weaknesses of the study were the slow speed of the equipment available at the project start (6 meters /

Table 1
FORMING WIRES STUDIED

Mesh	Material	Count/inch	Filament Shape	MD Wire Diameter (mm)	CD Wire Diameter (mm)	Open Area(%)
10	Polyester	11x11	Round	0.89	1.00	35
14	Polyester	14x13	Rectangular	0.40	0.40	25
36	Polyester	36x27	Round	0.11	0.14	29
100	Stainless Steel	100x90	Round	0.88 x 0.57	0.89	28

Table 2
FIBERS INVESTIGATED

Type	**Fiber Length mm**	**Dtex/Fil.**	**Coefficient Of Friction**	**Secant Modulus @ 2% n/dtex %**	**Density g/cm3**
PET 2	38	1.74	0.40	0.39	1.40
PET 4	38	1.67	0.47	0.26	1.39
PTT	38	1.89	0.47	0.14	1.32
Nylon 6	40	1.93	0.55	0.12	1.14
PP	38	1.74	0.48	0.22	0.91

minute,) and the hydroentanglement configuration of 3 strips on one side per pass. Laboratory upgrading has removed these restrictions from future work.

Experimental Procedure

Procedure details are available in reference (8). Carded, cross lapped webs were entangled using a 50.8 cm (20 inch) wide Honeycomb model hydroentanglement machine with three manifolds. Fabric samples were produced at different energy levels by varying both manifold pressure, and the number of passes through the machine. A minimum of two passes was required to treat both sides of the web and get good bonding. Such processing is typical of commercial multipass operation, but for this equipment manual rolling of the fabric between passes was employed. The pressure of the first manifold was held constant at 1.38MPa (200 psi) for prewetting. A maximum pressure of 10 MPa (1,450 psi) was available. Jet diameter was 0.127 mm with a jet density of 16 orifices/cm.

VARIABLES DRIVING HYDROENTANGLEMENT

Specific Energy

Specific energy delivered to the fabric was calculated in the traditional manner:

For 1 jet strip

$SE_s = f[(d_o^2, C_o, Pg^{1.5}, N)/WS]$, kJ/kg (1)

For the Total

$$SEt = \sum_{passes=1}^{n}\sum_{strips=1}^{m}(SE_s) \qquad (2)$$

where: d_o = jet diameter
C_o = discharge coefficient
P_g = jet manifold pressure
N = number of passes
W = fabric weight
S = Speed

The function is preceded by the appropriate constant for the input units used. In the case of these experiments jet diameter, fabric weight, and speed were generally maintained constant so specific energy is a function only of pressure and number of passes.

Jet to Fiber Drag Force

The force the jet delivers to a fiber was modeled as the drag resulting from a fluid passing by a cylinder, *Figure 6*.

Drag force across cylinders with nearly infinite length to diameter ratio has been well studied and can be calculated using Bernoulli's law, jet flow characteristics, and fiber dimensions. Details of this and all other force and energy calculations are contained in (8). This force is a function of the drag coefficient which is in turn a function of Reynolds number. For the range of variables studied,

- Coefficient of velocity 0.95
- Coefficient of discharge 0.62
- fiber diameter, mm (1.24 to 1.56×10^{-2})
- Jet diameter 0.127 mm
- Jet pressure (3.45 to 8.96 mPa)
- Water viscosity at 20°C

Reynolds number varies from 1,000 to 2,000. Consulting the Chemical Engineer's Handbook one discovers that over this range drag coefficient is invariant and equal 1.1. The final

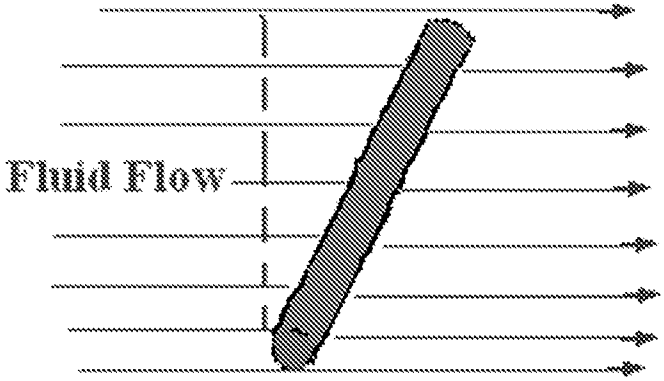

Figure 6
FLUID DRAG ON THE FIBER

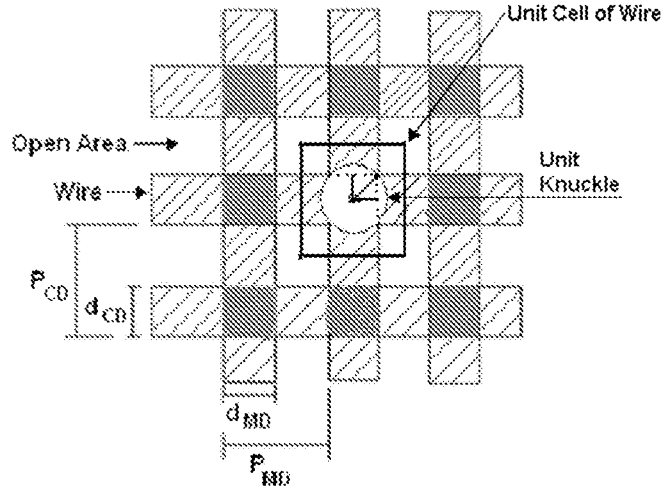

Figure 7
FORMING WIRE GEOMETRY

force equation becomes:

$$F_D = 0.99\ L_p d_f P_g \qquad (3)$$

Where: L_p = average projected fiber length, m which is assumed a function of the forming wire

d_f = fiber diameter, mm

Using this relationship one can calculate the average force a fiber feels during the hydroentangling process.

VARIABLES RESISTING HYDROENTANGLEMENT - A PHYSICAL MODEL OF HYDROENTANGLEMENT

As indicated in *Figures 2, 3, and 4*, hydroentanglement can be visualized as the formation of a structure with defined unit cells from a random oriented input web. Input energy and drag force drive the formation of the fabric cell structure. These factors are resisted by:

- Fiber bending force
- Fiber to fiber friction force
- Stress resulting from fiber strain

In this initial treatment, fiber to forming wire frictional force is assumed negligible, although it is probably proportional to fiber to fiber friction and lumped into that variable. To estimate the magnitude of these forces a simple physical model was developed to estimate:

- The size of the cellular structure based on the forming wire
- The magnitude of each force
- The total energy consumed by the fabric process assuming all are operative.

The Unit Cell

The size of the cellular structure in the fabric is a function of the geometry of the forming wire. *Figure 7* illustrates a typical forming wire.

At each point in the weave pattern where one wire crosses over the other a raised area or "knuckle" occurs. The size of this knuckle can be geometrically calculated from the wire specifications (8):

- d_{MD} and d_{CD}, wire diameters in MD and CD respectively
- P_{MD} and P_{CD}, wire spacing in MD and CD respectively

Given the size of the unit knuckle the size of the unit cell can be estimated from the intersections of the weave pattern.

Fiber Bending Force

Figure 8 is a schematic of the transformation a fiber undergoes if it slides strain free from the straight configuration in the input web to a position conforming to the unit cell.

The fiber bending force, or flexural rigidity, can be calculated using standard methods (8) and is:

$$\langle FR \rangle = 7.96\text{x}10^{-2} ET^2/\rho \qquad (4)$$

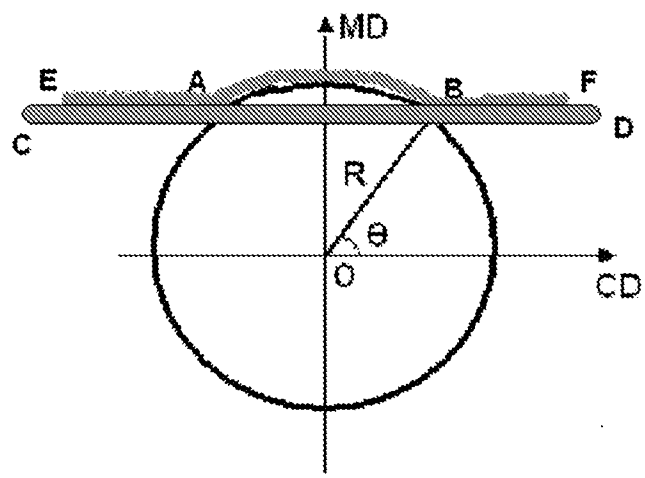

Figure 8
FIBER GEOMETRY CHANGE WITH 0 STRAIN

Where: E = Young's modulus at 2% strain, N/m²
T = Fiber linear density, kg/m
_ = Fiber density, g/m³

Frictional Force

Frictional force can be estimated from the standard $F = \mu N$ with the result:

$$F_f = 1.49x10\text{-}8\mu_w P_g \qquad (5)$$

Where: μ_w = fiber to fiber coefficient of friction
P_g = jet manifold pressure, mPa

It is interesting to observe that increasing the jet manifold pressure actually increases the frictional force resisting hydroentanglement because it is the normal force in the friction equation.

Fiber Force from Strain

If both ends of a fiber are pinned by the developing fabric structure the fiber must undergo strain to conform to the unit cell as indicated in *Figure 9*.

Two assumptions are used to calculate the strain:

- Restrained points are at the middle of the wire spacing
- The fiber is strained to conform to the unit cell.

The resulting strain force is:

$$F_s = 1.14RET/K_w \qquad (6)$$

Where: E = Young's modulus, N/m²
T = fiber linear density, kg/m
K_w = the forming wire spacing, mm
R = diameter of unit hole, mm

CALCULATED ENERGY UTILIZATION

The definition of work, resistance forces, fiber properties, and unit cell dimensions can be used to estimate the work done to transform a uniform random web to the unit cell structure. Unit cells observed on test fabrics corresponded closely with those calculated from wire geometry.

$$W = \int_o^D F dx \qquad (7)$$

As seen from *Figure 1*, maximum properties for both PET and PTT appear to develop at a specific energy of approximately 5,000 kJ/kg fabric. We used this energy level to calculate what fraction of the input energy was actually used in fabric bonding with the following assumptions, 1) that all fibers obtained the unit cell geometry and 2) that all three forces were involved to their maximum extent. This should give an upper limit estimate of energy utilization. A typical 100% PET fabric was used for the calculation, details of which are presented in (8). Results presented in *Table 3* indicate that only a small amount of input energy is used to construct the bonds. Interestingly, the energy consumed is relatively independent of the size of the unit cell (forming wire mesh) because while fine meshes provide less fiber movement, there are many more cells per unit area. Even if this estimate is an order of magnitude low, it is evident that the actual amount of energy used is less than 10%.

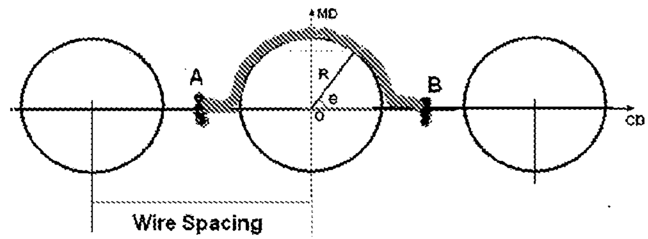

Figure 9
FIBER GEOMETRY WITH STRAIN

These results lead one to question the use of specific energy to describe the hydroentanglement process.

FORCE OR SPECIFIC ENERGY?

A simple way to test whether force or energy is the determining variable is to produce samples at the same specific energy by two different routes. Specific energy can be increased by either 1) increasing manifold pressure, or 2) increasing the number of passes at a low manifold pressure. Typical results from such an experiment, illustrated in *Figures 10 and 11*, show that specific energy does not uniquely correlate fabric tensile behavior in either MD or CD when multiple passes are used.

While we were not surprised that specific energy was not the prime driver for tensile property development, we were surprised at the direction of the improvement in machine direction, with the lowest jet pressure (force) yielding the best fabric tensiles. The key to this difference lies in the effect of the forces required to transfer the fabric from one pass to another which change the fabric fiber orientation distribution function by "drawing" the fabric.

Fabric responses appear force driven, rather than energy driven. It is clear that transfer forces are important and should be further studied. This paper, however, focused on the forces in the hydroentangling zone.

Table 3
ESTIMATED ENERGY UTILIZATION IN HYDROENTANGLING 100% PET

Mesh	Bending Work kJ/kg	Friction Work kJ/kg	Strain Work kJ/kg	% Energy Used
10	0.008	17	17	0.7
14	0.012	22	31	1.0
36	0.063	24	35	1.2
100	0.580	17	20	0.8

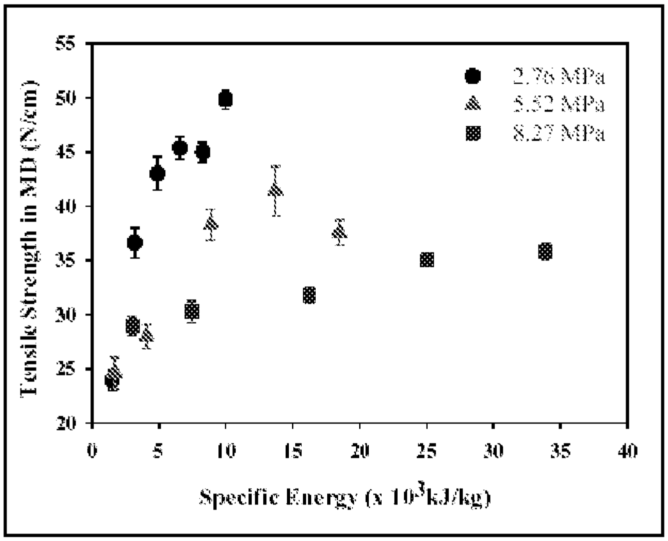

Figure 10
SPECIFIC ENERGY TENSILE STRENGTH IN CD DIRECTION

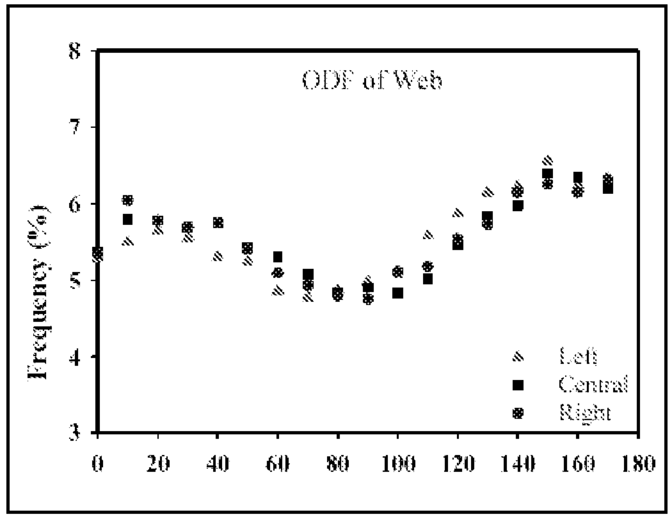

Figure 12
INPUT WEB FIBER ORIENTATION

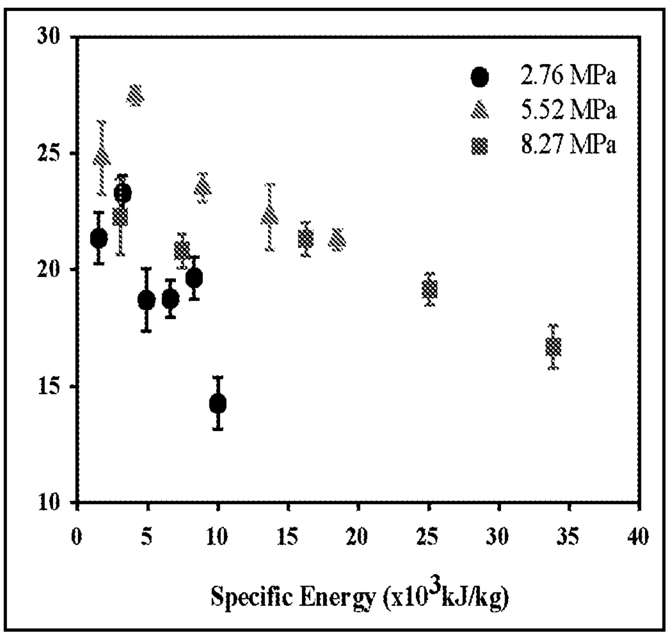

Figure 11
SPECIFIC ENERGY TENSILE STRENGTH IN CD DIRECTION

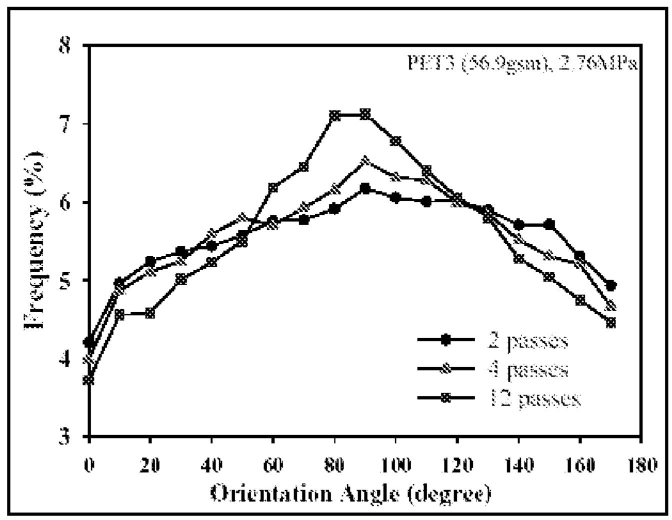

Figure 13
EFFECT OF INCREASED HYDROENTANGLEMENT PASSES ON FIBER ORIENTATION

Fabric Transfer Force

Fabric transfer force was not measured quantatively during these trials, because the transfer between passes was done by hand. However, qualitatively, the higher the jet pressure, the higher the transfer force. We also found that increasing the number of transfers changed the fabric geometry and caused a measurable difference in the fiber orientation distribution.

Figure 12 is the fiber orientation distribution (ODF) of the web fed to the hydroentangling process. This orientation distribution with dual maxima near 20 and 160º are what would be expected for a cross lapped card web.

Figure 13 indicates that hydroentangling converts this fiber distribution to one with primary machine direction orientation, and that this machine direction bias increases with increasing number of passes at constant pressure. *Figure 13* is for a relatively low jet pressure, the effect is more profound at higher pressures.

It is clear that both the number of fabric passes from belt to belt as well as the transfer force required are important variables and should be carefully controlled.

DIMENSIONAL ANALYSIS

Dimensional analysis in the form of force ratios has been used for generations to describe complex fluid flow and heat transfer systems. For example, Reynolds number, the ratio of

viscous to inertial forces for fluid flow describes drag coefficients, pipe pressure drops, and the onset of turbulence. Having estimated the forces resisting hydroentanglement, and the jet drag force which causes it, dimensionless numbers can be generated by ratioing a given resistance force to the drag force. These numbers might be used to determine the primary resistance force to hydoentanglement in a given forming wire, and fiber content regime.

Flexural Rigidity Ratio

Equations 3 and 4 can be used to calculate the flexural rigidity ratio as follows:

$\phi_{FR} = F_d/\langle FR\rangle = (0.99\ L_p d_f P_g)/[7.96\times10^{-2}(ET^2/\rho)] = 12.4\ L_p d_f P_g \rho/(ET^2)$ (8)

This dimensionless number is a function of jet pressure to the first power, forming wire dimensions, and fiber properties. When fiber bending dominates we would expect fabric properties to change linearly with jet pressure with the rate proportional to the fiber and wire properties.

8.2 Fiber Friction Ratio

Equations 3 and 5 can be used to construct the friction ratio as follows:

$\phi_f = F_d/F_f = (0.99\ L_p d_f P_g)/(1.49\times10^{-8}\mu_w P_g) = 6.08\times10^{7}(L_p d_f)/\mu_w$ (9)

This dimensionless number is independent of jet pressure and is influenced only by forming wire and fiber properties. When fiber friction dominates we would expect fabric properties to be nearly invariant with jet pressure.

Stress/Strain Ratio

Equations 3 and 6 can be used to calculate the stress/strain ratio as follows:

$\phi_s = F_d/F_s = (0.99\ L_p d_f P_g)/[1.14(RET/K_w)] = 0.87(L_p d_f P_g K_w)/(RET)$ (10)

This dimensionless group is proportional to jet pressure and a function of both fiber properties and forming wire geometry, but in a different way than the flexural rigidity ratio. One therefore expects fabric properties to vary linearly with increasing pressure.

DIMENSIONAL ANALYSIS APPLIED

Trials were run with all four wire types in *Table 1*, and fibers in *Table 2*, using only two passes at a series of pressures from about 3.5 to 10 mPa. The area of interest in these data is the area from low pressure to the pressure at which fabric properties reach a maximum. Fabric tensile responses for this experiment plotted in *Figure 14* indicate a linear pressure response for all fibers up to maximum property development. *Figure 15* is the regression analysis for the linear portion of the *Figure 14* indicating good fit to linearity. *Table 4* contains values of the slope for the pressure - tensile correlation. Since the fabric is responding linearly with pressure, the friction

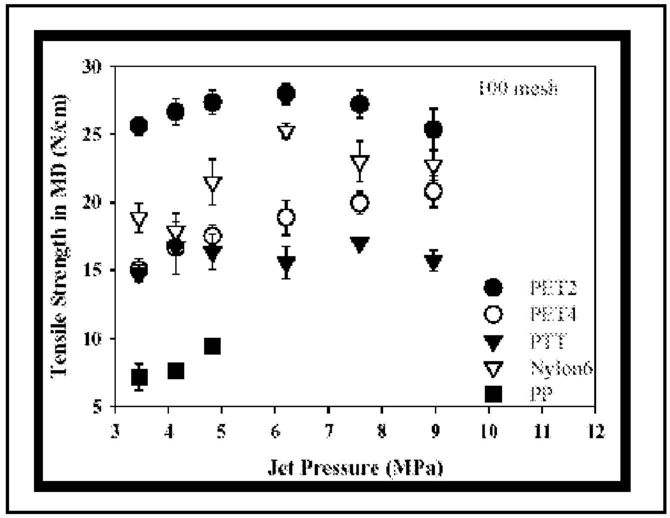

Figure 14
TENSILE STRENGTH DEVELOPMENT WITH INCREASING PRESSURE, 100 MESH

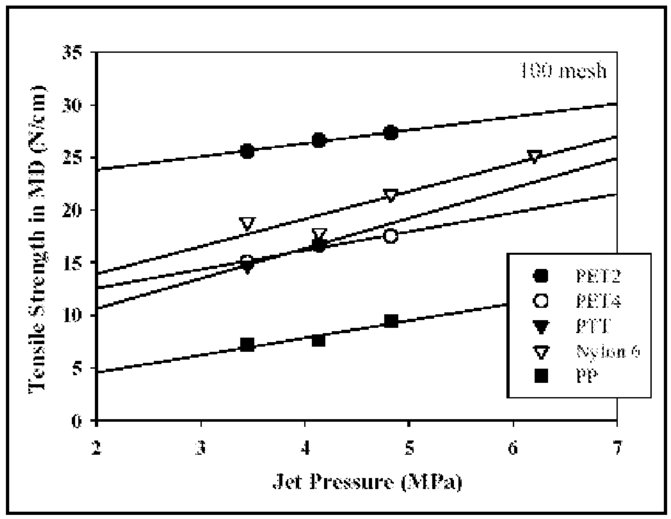

Figure 15
REGRESSION ANALYSIS OF LINEAR PORTION OF STRENGTH / PRESSURE

Table 4
PRESSURE, TENSILE PROPERTY LINEAR CORRELATION RESULTS

Fiber Type	Intercept N/cm	Slope N/cm mPa	Correlation Coefficient, R2
PET2	21.3	1.26	0.99
PET4	9.0	1.79	0.97
PTT	4.9	2.86	1.00
Nylon 6	8.7	2.61	0.87
PP	1.3	1.64	0.88

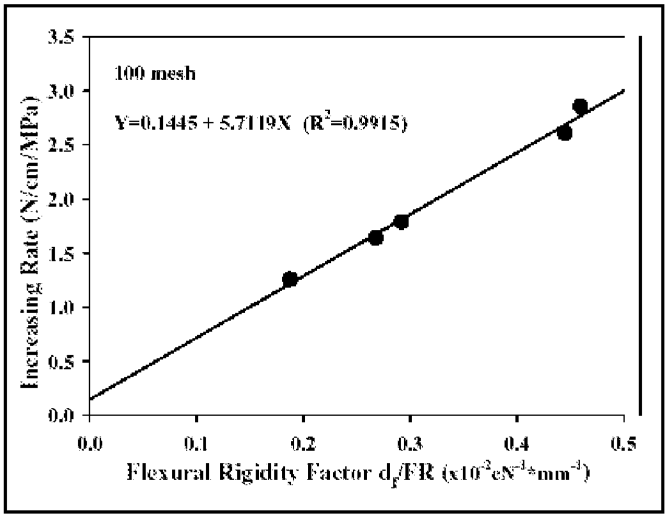

Figure 16
SLOPE CORRELATION WITH FLEXURAL RIGIDITY RATIO 100 MESH

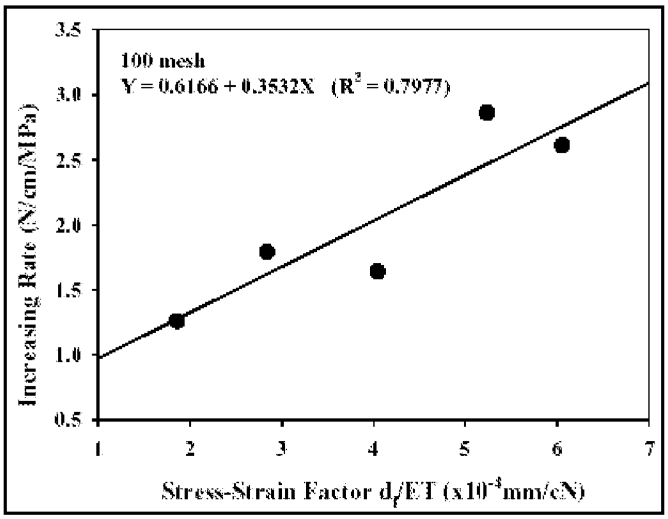

Figure 17
SLOPE CORRELATION WITH STRESS/STRAIN RATIO 100 MESH

ratio is eliminated as the major driving force.

Flexural rigidity ratio and stress/strain ratios can be tested by examining goodness of fit of the slopes as a function of these ratios. Such a plots are contained in figures 16 and 17 and indicate that the dominate mechanism is probably flexural rigidity.

Mesh Results

As indicated in *Figure 18*, results from the very open 10 mesh screen was very different, with tensile strength independent of jet pressure for all fibers tested. We believe this indicates that the friction ratio is the dominate factor.

Results from the intermediate mesh screens provided no clear guidance as to dominant mechanism, indicating a transition region where several mechanisms are important. Overall results summarizing dominant mechanism are presented in Table V. Clearly more work is required over a wide range of screens and fibers at realistic operating speeds to fully develop use of the unit cell and dimensional analysis concepts.

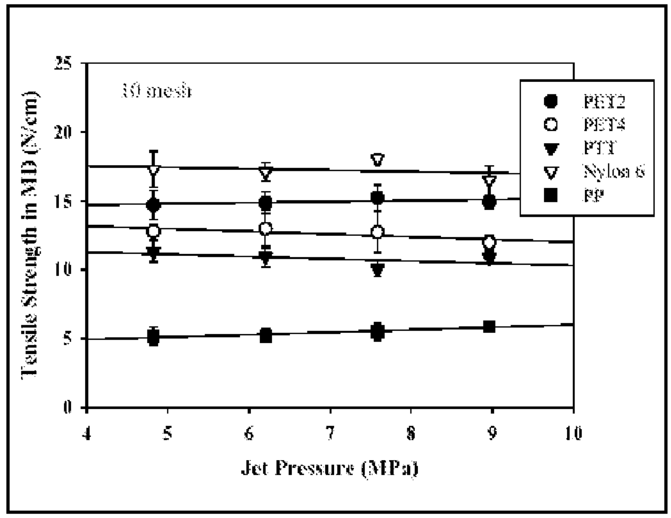

Figure 18
TENSILE STRENGTH DEVELOPMENT FOR10 MESH SCREENS

Table 5
DOMINATE FORCE MECHANISM

Forming Wire	**Mechanism**
10 Mesh Round	Friction
14 Mesh Rectangle	Transition
36 Mesh Round	Transition
100 Mesh Round	Flexural Rigidity

SUMMARY AND CONCLUSIONS

A mechanical model describing the transformation of the web structure from randomly arranged fibers to a well organized unit cell structure is developed. This cell model is used to quantify the jet drag force which drives this rearrangement and the three major fiber forces resisting it:

- Fiber bending rigidity
- Fiber to fiber friction
- Forces resulting from fiber strain.

These forces are used to calculate the work used to rearrange the fabric into the unit cell structure. This work is found to be around 1% of the input energy. Experimental work in which specific energy was varied by both jet pressure and repeated passes through the unit confirmed that jet force, and not specific energy, is the variable responsible for hydroentanglement. In the course of this experiment the impact of the transfer force between passes and the number of passes on fabric properties was observed. Both variables are important to the hydroentanglement process.

Finally, dimensional force groups were shown to have

promise for correlating hydroentanglement performance. Additional work at higher production speeds and pressures with a variety of fibers on diverse forming screens is required to exploit this initial finding.

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